Retrieval of CO_2 Using AIRS and IASI

Breno Imbiriba, L. Larrabee Strow, Scott Hannon, Sergio DeSouza-Machado, and Paul Schou

Atmospheric Spectroscopy Laboratory (ASL)
Physics Department *and*
Joint Center for Earth Systems Technology
University of Maryland Baltimore County (UMBC)

AIRS Science Team Meeting
Nov. 3-5, 2010, Greenbelt, MD

ASL

Overview

(Thanks to Jean-Nöel Thépaut of ECMWF for providing missing ECMWF data.)

- Understanding the carbon-cycle and its change with time is clearly a key activity in climate change.
- GOSAT and OCO concentrating on observations for inverse modeling, which requires highly accurate measurements. Too early to evaluate.
- But, GOSAT and OCO are column measurements, which require accurate transport models for the flux inversion. Are these models accurate enough?
- Hyperspectral infrared sees up to 60% of the CO_2 column and may be essential for interpreting satellite column measurements.
- New: (1) Full RTA corrections (secant angle), (2) interpolate ECMWF in time. Now agreement between day/night, LW/SW! Mostly reporting SW day, lower noise, better cloud detection.

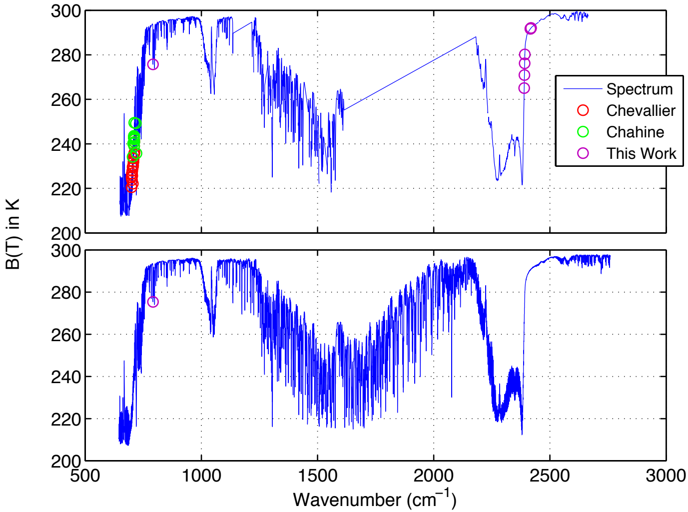
The Role of Hyperspectral Infrared

- Hyperspectral IR sensitive to CO_2, but difficult to untangle CO_2 from the temperature profile, clouds, and the surface. Plus individual spot noise is high.
- Various authors have assimilated, or retrieved CO_2 using AIRS, *but* using mid- to upper-tropospheric channels.
- Assimilation: Chevallier and Engelen et.al.; Retrievals: Chahine et.al. and Crevoisier et.al.
- Assimilation results are disappointing, partly the result of observations too removed from the source or poor transport when coupled to flux variations. But, also due to difficulty in background error when used with spatially inhomogenous selection of observations.
- This work: Examine CO_2 retrieved from lower-peaking channels sensitive to the surface. Essentially bias evaluation using ERA-Interim and/or ECMWF 3-hour forecasts for the hard part, T(z).
- My Goal: Assimilators: Don't give up on hyperspectral infrared for CO_2 research, use lower peaking channels.

Approach

- ECMWF uses radiosonde measurements as the "anchoring network" of observations for the ECMWF tropospheric temperatures with no bias correction, see Auligne, T., A. McNally, and D. Dee (2007), Adaptive bias correction for satellite data in a numerical weather prediction system, QJRMS, *133*, 631–642, doi10.1002/qj.56.
- They take out the CO_2, *very accurately*
- Our retrieval:
  - Find clear scenes (hard part). Remove all cirrus. This drastically lowers yield.
  - Match ERA/ECMWF to the scene (needs to be better).
  - Improve total column water.
  - Compute the radiances, and using 2-8 channels solve for the surface emission and the best offset to a fixed CO_2 profile with unconstrained least-squares.
  - QA the output (and save the kernel).
- Two channel sets: 1. (LW) 790.3 cm^{-1} (T_{sfc}) and 791.7 (T_{sfc} and CO_2) or, 2. (SW) 2390-2418 cm^{-1} channels all with surface and CO_2 sensitivity.

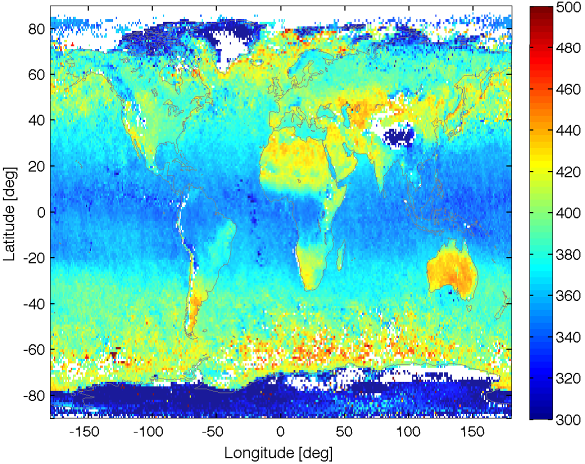
Spectra Showing Channels Used for CO_2 Retrievals



Altitude Sensitivity of Kernel

Chahine, ECMWF, Chevallier Kernels peak at 250-300 mbar

Land kernel functions decrease to ~50% around 700 mbar.
This image shows the location of the kernel peak



Adantages/Disadvantages of LW vs SW Retrievals

- Longwave
  - Lower temperature dependence
  - Sensitive to cirrus and water vapor continuum
  - Slightly sensitivity to CCl_4 and PAN
  - Insensitive to instrument spectral calibration
  - High noise (only 2 channels)
  - Required significant effort to improve RTA relative accuracy to well below 0.1K (water variability).
- Shortwave
  - Higher temperature dependence
  - Insensitive to water (almost)
  - Sensitive to N_2 continuum
  - Some sensitivity to instrument spectral calibration
  - Lower noise by using ~8 channels
  - More sensitive to aerosols
  - RTA needs good non-LTE emission for daytime retrievals.

Remember: 1 ppm CO_2 = 0.02 to 0.03 K in B(T)!

Cal/Val With NOAA's GlobalView Sites

- Use NOAA's GlobalView data set (http://www.esrl.noaa.gov/gmd/ccgg/globalview)
- Product is directly driven by measurements.
- Focus on airplane sites and Mauna Loa.
- GlobalView's time series are linearly interpolated to AIRS measurement times. Usually we use the highest altitude flights.
- Simulations show we are not sensitive to the boundary layer, so direct use of flight values is warranted.

Shortwave and longwave night agree well with each other and with longwave daytime. Shortwave daytime is offset by 3 ppm (non-LTE). Mostly use shortwave daytime since it gives (a) better S/N, and (b) daytime cloud screening is better.

Validation (including Seasonal Cycle Amplitude, all units in ppm)

Validation very difficult, will require long-term attention. Bias already includes 3 ppm offset.

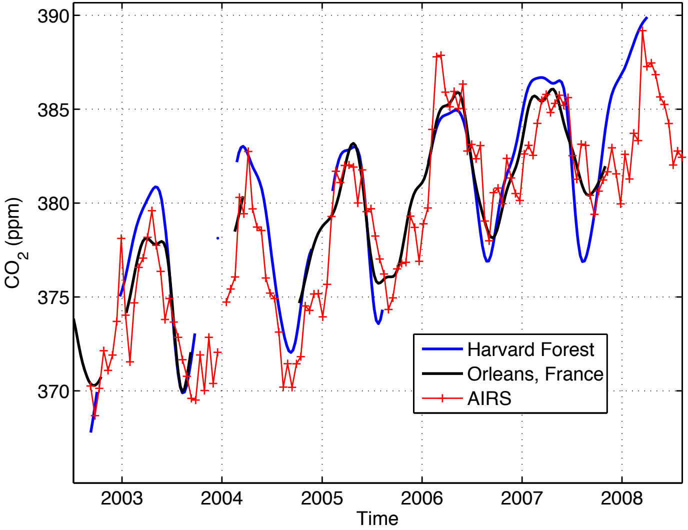
Station	Latitude	Bias	Seasonal Cycle (Obs)	Seasonal Cycle (GV)	Obs-GV	Comment
bne	41	-0.7	3.8	3.5	0.3	
dnd	48	-2.3	4.3	3.9	0.4	
esp	49	1.1	3.3	4.3	-1.0	land/ocean
haa	21	0.5	2.8	2.4	0.4	
hfm	43	-0.9	2.2	3.5	-1.3	phase shift
hil	40	-1.7	3.3	3.2	0.1	
mlo	20	0.7	2.7	3.2	-0.5	
nha	43	-0.4	2.0	3.8	-1.8	phase shift
orl	48	1.7	3.1	4.6	-1.5	phase shift
pfa	65	2.1				no winter obs
rta	-21	1.3	1.7	0.1	1.6	very little data
tgc	28	-0.3	3.8	3.0	0.8	
thd	41	0.8	2.6	3.5	-0.9	
		0.1 $\pm$1.3				

Given the altitude (and phase) dependence of CO_2, validating a measurement with a deep kernel is challenging. For example, “age-of-air” is not included here.

ASL

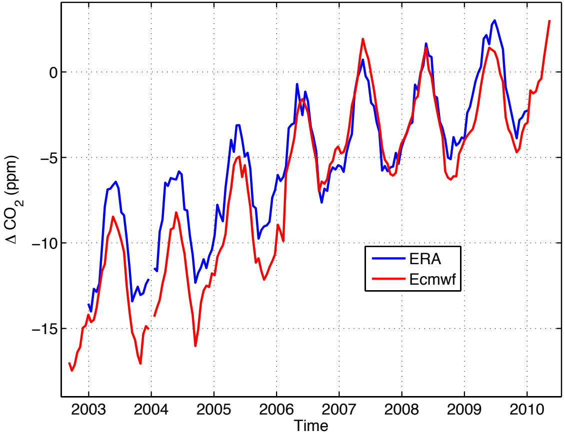
CO_2 Validation Time Series

Observations within 4 deg lat/lon. AIRS daytime, shortwave data.



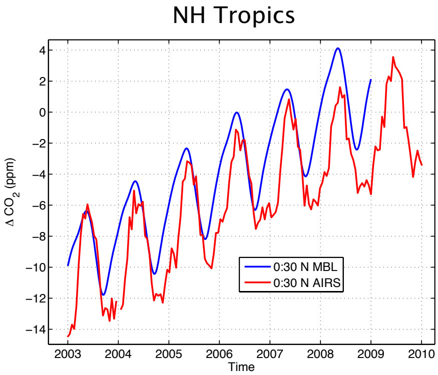
CO_2 Time Series: ECMWF vs Interium-ERA

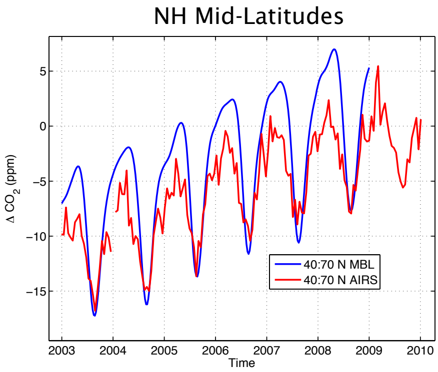
This is a NH zonal 0-50 deg average over ocean.



Use ECMWF for mapping (we interpolate between the 3-hour forecasts), use ERA for zonal time series analysis.

CO_2 Time Series: Hyperspectral vs Marine Boundary Layer

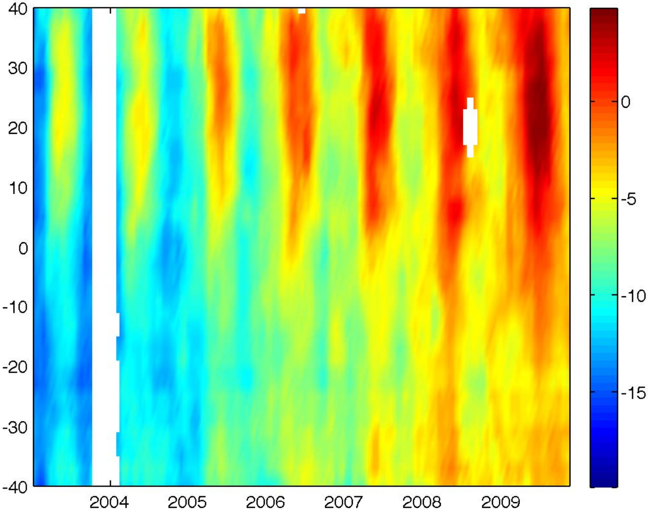




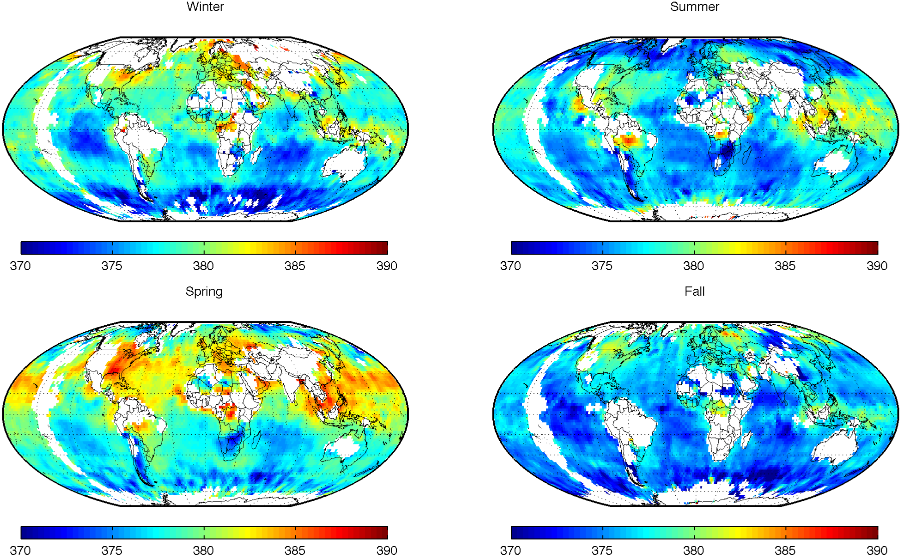
Ocean Zonal CO_2 over Time

CO_2 Growth and Seasonal Patterns Appear Realistic

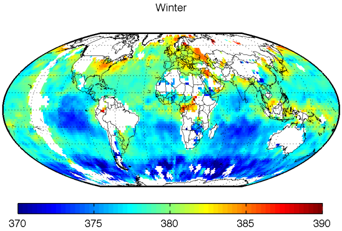
Vertical scale: latitude; Horizontal: time, color is change in CO_2 in ppm.



AIRS Observed Seasonal CO_2 Variability

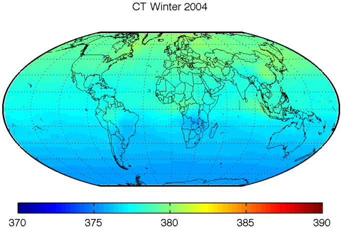


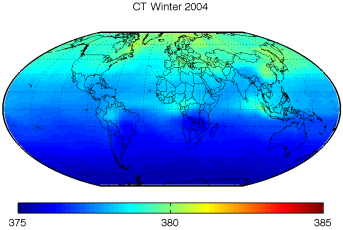
AIRS CO_2 Shows More Variability than CarbonTracker



Winter

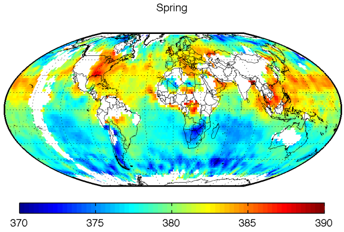
- At left: AIRS in Winter, data adjusted to 2004
- Below Left: CarbonTracker convolved with AIRS kernel
- Below Right: CarbonTracker scale reduced by 10 ppm





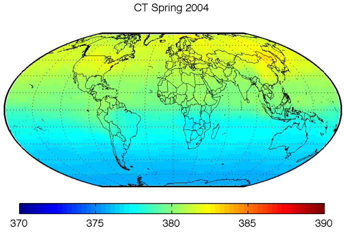
Note reduced scale above.

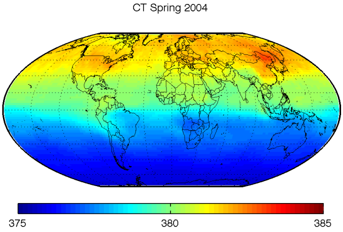
AIRS CO_2 Shows More Variability than CarbonTracker



Spring

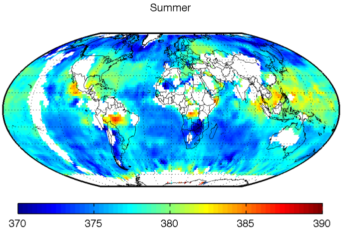
- At left: AIRS in Spring, data adjusted to 2004
- Below Left: CarbonTracker convolved with AIRS kernel
- Below Right: CarbonTracker scale reduced by 10 ppm

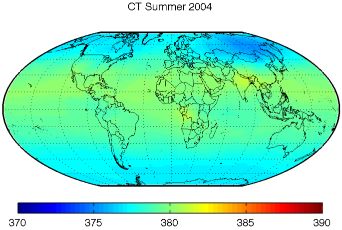




Note reduced scale above.

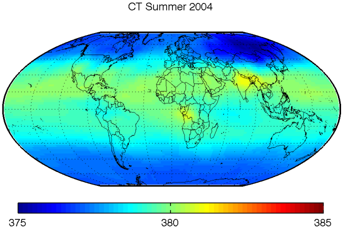
AIRS CO_2 Shows More Variability than CarbonTracker





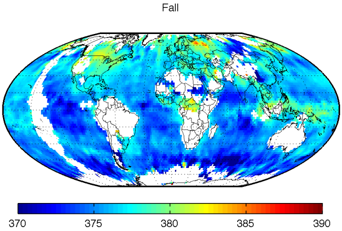
Summer

- At left: AIRS in Summer, data adjusted to 2004
- Below Left: CarbonTracker convolved with AIRS kernel
- Below Right: CarbonTracker scale reduced by 10 ppm



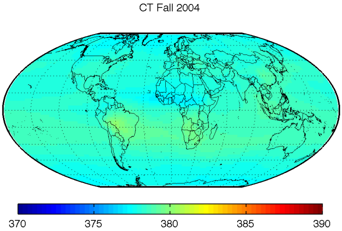
Note reduced scale above.

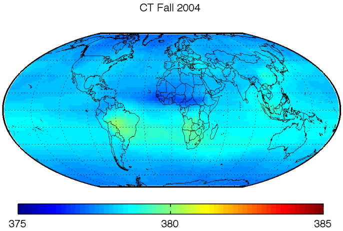
AIRS CO_2 Shows More Variability than CarbonTracker



Fall

- At left: AIRS in Fall, data adjusted to 2004
- Below Left: CarbonTracker convolved with AIRS kernel
- Below Right: CarbonTracker scale reduced by 10 ppm

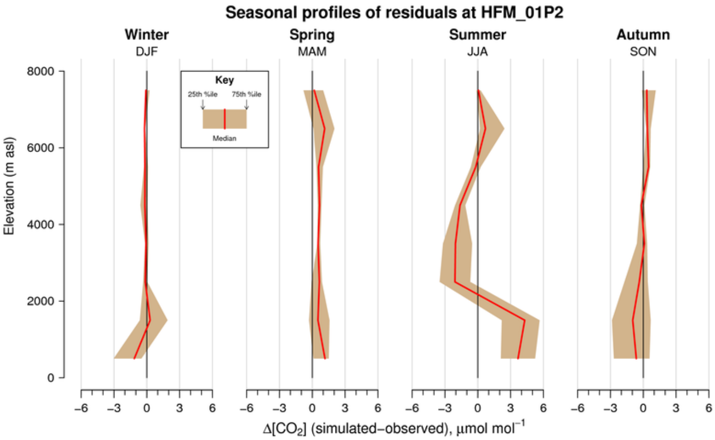




Note reduced scale above.

CarbonTracker versus Aircraft Observations

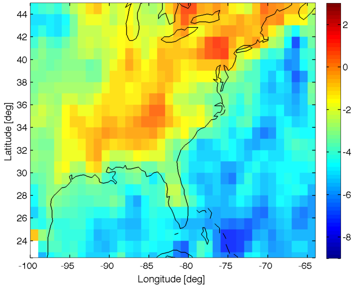
CT does not assimilate aircraft data.

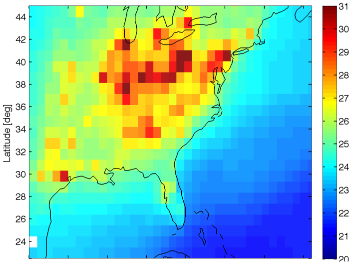


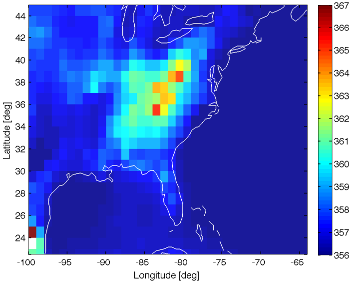
Note relatively high errors in summer. With AIRS kernel functions this oscillation will not average out.

Patterns of AIRS CO_2 during Fall Season: Eastern US

Fall is best time to see anthropogenic emissions.



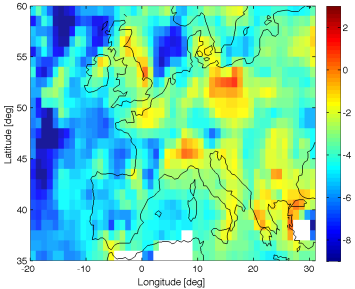


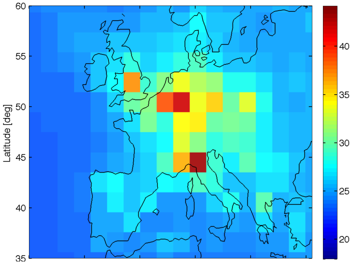


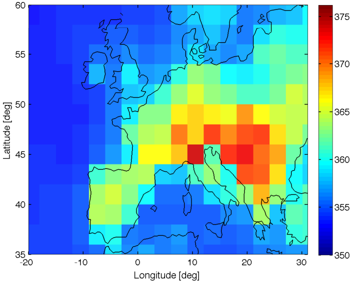
- Above: AIRS Observations
- Top Right: CarbonTracker Fossil Fuel
- Bottom Right: CarbonTracker Natural

Patterns of AIRS CO_2 during Fall Season: Europe

Fall is best time to see anthropogenic emissions.





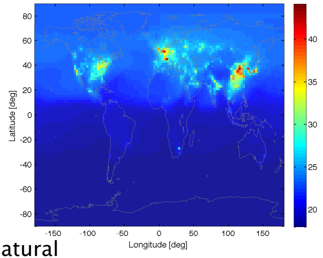


- Above: AIRS Observations
- Top Right: CarbonTracker Fossil Fuel
- Bottom Right: CarbonTracker Natural

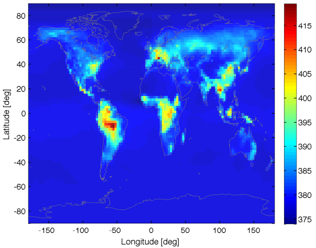
CO_2 Maps with less restrictive cloud filtering

CarbonTracker Surface vs AIRS CO_2

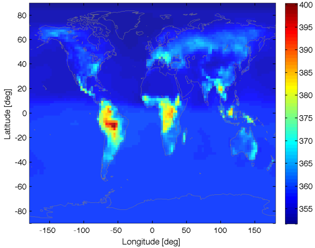
Fossil Fuel

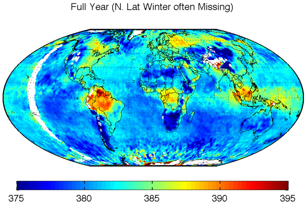


Combined



Natural

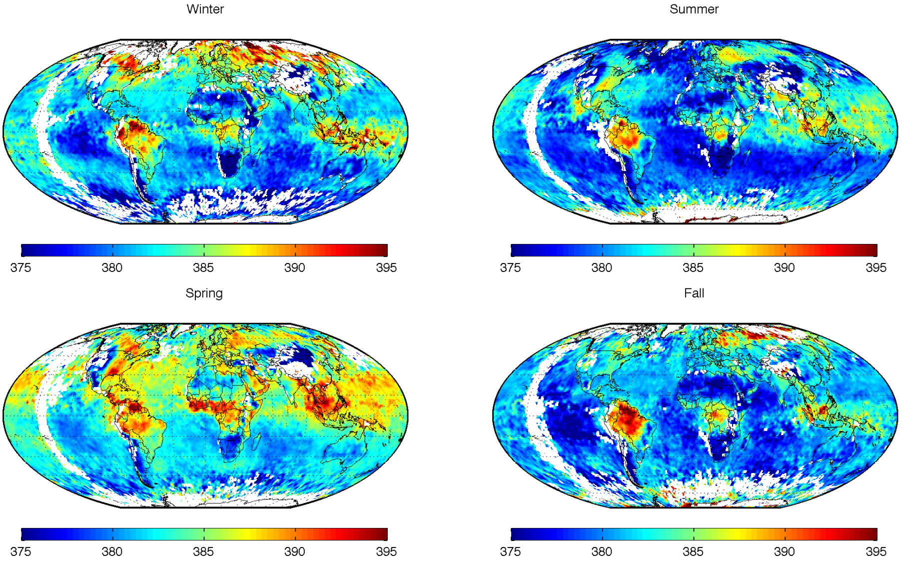




ASL

CO_2 Maps with less restrictive cloud filtering

Seasons



Conclusions

- Hyperspectral IR radiances are providing information that is not in the models. Mostly transport?
- CO_2 features appear reasonable, but have more contrast than models.
- Use hyperspectral IR in conjunction with GOSAT and OCO.
- Combination of assimilated data for meteorological profiles, simple retrieval for minor constituents using surface affected channels appears to be quite powerful.
- What errors are introduced by ECMWF models?
- Lower cloud QA to see if yield can be increased for inverse modeling?
- Can ECMWF provide minor constituent retrieval community with higher temporal resolution reanalysis???